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EXECUTIVE SUMMARY

SUPPLEMENTARY ELECTRIC HEATING - STATE-OF-THE-ART

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This report presents an outline of the opportunities for electric heat as a supplementary heat source in existing homes.

It has been estimated that existing homes will constitute three-quarters of the housing in fifteen years. Many of these homes will have old inefficient heating systems with comfort problems caused by such factors as inadequate ducting, poor air register location, and rooms with changing comfort requirements.

A study was undertaken at the end of 1983 to look at the supplementary electric heating equipment both available and soon-to-be available. A summary of the available equipment is shown in Table 1.

An attempt was also made to identify areas where product acceptability could be increased with assistance provided by Ontario Hydro. These areas included:

1. Controls which match the heat supplied by a plenum heater to the heating demand, on a continuous basis.

2. A furnace blower control which maintains the supplied air at a certain temperature by controlling the air flow rate.

3. Laboratory and field tests to alleviate "first generation" problems in microprocessor controlled heat pumps (controls used for defrost cycling and mechanical failure detection).

job	file	date	report no.
740612-116-111	814.345	May 30, 1984	84-148-K

TABLE 1

SUMMARY OF AVAILABLE SUPPLEMENTARY ELECTRIC HEATING EQUIPMENT

Type of Supplementary Heating	Main Advantages (other than energy costs)	Main Disadvantages	Cost
1. baseboard heaters	-allows easy zonal temperature control	-requires space for air circulation (convective heaters) or open areas (radiant heaters)	$100/ room
2. plenum heaters	-easily installed -uses a central forced air system	-cooler air delivery temperature than during normal furnace operation -may require an upgrade of the electrical service entrance	$1000
3. add-on heat pump	-provides air conditioning as well as heating -used with central forced air system -supplies more energy than it uses	-cooler air delivery temperatures than during normal furnace operation -may require an upgrade of the electrical service entrance -higher maintenance costs	$3000
4. wall unit heaters	-suited for hard to heat areas (bathrooms, entrance halls)	-may require structural changes to install the heaters	$300 (kick space and wall insert) to $1200 (cabinet)
5. ceiling units	-good for small areas or specific objects in large areas (ie garages)		$100 +
6. portable heaters	-good solution for temporary heat demands	-requires enough space for heater and air circulation -extended use may affect the life of circuit wiring	$50 +
7. floor insert heaters	-counter cold drafts from windows	-requires housekeeping to keep free of dirt	$200

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To Mr. R.H. Stewart
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SUPPLEMENTARY ELECTRIC HEATING - STATE-OF-THE-ART

F.G. Pellini and B.G. Woods

The opportunities for electric heating as a supplementary source in existing homes were studied at the end of 1983. The study included a state-of-the-art look at what equipment is available and what is likely to become available. Also, an attempt was made to identify areas of possible future development to make supplementary electric heating more acceptable.

1.0 INTRODUCTION

The potential market for supplementary electric heating is in residences where at least one of two situations exist. The first situation is where supplementary heaters can displace a large portion of an oil furnace's oil consumption and thus reduce the heating costs. The second situation is where comfort can be improved with supplementary heating equipment. The higher comfort levels could be achieved by more closely controlling individual room temperatures according to their use (ie nurseries may have to be kept warmer than storage areas) or by reducing the fluctuation of room temperatures.

2.0 SUMMARY OF SUPPLEMENTARY ELECTRIC HEATING EQUIPMENT AND THEIR APPLICATIONS

The general types of supplementary electric heating equipment are outlined in Table 2, along with the advantages and disadvantages of the equipment, and their approximate installed cost.

The possible applications for supplementary electric heating in the main types of existing heating systems, are summarized in Table 3.

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TABLE 2

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1. baseboard heaters	-allows easy zonal temperature control	-requires space for air circulation (convective heaters) or open areas (radiant heaters)	$100/ room
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4. wall unit heaters	-suited for hard to heat areas (bathrooms, entrance halls)	-may require structural changes to install the heaters	$300 (kick space and wall insert) to $1200 (cabinet)
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7. floor insert heaters	-counter cold drafts from windows	-requires housekeeping to keep free of dirt	$200

TABLE 3

APPLICATIONS FOR SUPPLEMENTARY ELECTRIC HEATING WITH EXISTING HEATING SYSTEMS

	Forced Air Systems	Hydronic Systems	Zonal Systems	Gravity Systems
baseboard heaters	-supply a changing or increased heating demand in an area -when located below windows, they could even the temperature distribution in rooms with inside wall duct systems -can be used in a dual fuel system to reduce fuel costs	-supply a changing or increased heating demand in an area -can be used in a dual fuel system to reduce fuel costs	-upgrade the heating in individual areas -can be used in a dual fuel system to reduce fuel costs	-ensure a minimum temperature in rooms that are isolated -can be used in a dual fuel system to reduce fuel costs
plenum heaters	-can be installed in oil furnaces to reduce fuel costs and provide heat with air circulation	-not applicable	-not applicable	-not applicable
add-on heat pumps	-can be installed to reduce fuel costs, and provide heating and air conditioning with air circulation	-not applicable	-not applicable	-not applicable
wall unit heaters	-supply changing heat demands (ie entrance halls) with minimum affect on adjoining rooms	-supply changing heat demands (ie entrance halls) with minimum affect on adjoining rooms	-supply changing heat demands (ie entrance halls) with minimum affect on adjoining rooms	-supply changing heat demands (ie entrance halls) with minimum affect on adjoining rooms
ceiling unit heaters	-radiant heaters can replace space heating in large areas (ie work areas or garages)	-radiant heaters can replace space heating in large areas (ie work areas or garages)	-radiant heaters can replace space heating in large areas (ie work areas or garages)	-radiant heaters can replace space heating in large areas (ie work areas or garages)
portable heaters	-supply sporadic heat demands	-supply sporadic heat demands	-supply sporadic heat demands	-supply sporadic heat demands
floor insert heaters	-counters cold drafts below windows	-counters cold drafts below windows	-counters cold drafts below windows	-counters cold drafts below windows

3.0 EXISTING HEATING SYSTEMS

There are various types of residential heating systems presently installed. To assist in the evaluation of the potential for supplementary electric heating, brief descriptions of the various heating systems are given. Also, there is additional attention to factors which may affect supplementary heating possibilities.

3.1 Forced Air Heating System

The most common form of residential heating is the forced air heating system. The forced air system uses a central heat source and distributes heated air throughout the residence via a system of ducts.

The principal energy sources for forced air systems are gas, oil, and electricity. Also, additional equipment such as heat pumps, solar collectors, or air conditioners can be easily accommodated by placing a heat exchanger in the air stream.

The air distribution, or duct, systems can be classified into two groups:

1. Inside wall systems, in which supply outlets are on the inside walls with the return air openings near the outside walls.

2. Perimeter systems, in which the supply outlets are at or near the floor along the outside walls, and the return air openings are along the inside walls or in the centre of the structure.

A properly installed forced air system with a correctly sized furnace will provide an excellent level of comfort. This level of comfort will be compromised to some degree though, if the furnace is improperly sized, if the air flow is restricted by objects in front of registers, or if the thermostat is improperly located.

3.2 Hydronic Heating System

Another type of residential heating system is the hydronic system. The heart of this system is a central hot water or steam boiler which uses either gas, oil or electricity as the energy source. The heated fluid is distributed by a system of piping to baseboard convectors or fan-coil units located in each room. There are three basic types of hydronic distribution systems:

1. Series loop system, in which the heated fluid flows through each heat exchanger in succession.

2. One pipe system, in which the heaters tap into a single pipe with valves controlling the flow to each heat exchanger.

3. Two pipe system, in which there are separate mains for supply and return water.

In residences with hydronic systems, a high level of comfort can be obtained. Although, in houses where certain rooms depend on the distribution of warm air to meet some of the heating demand (ie, second storey rooms in multi-storey houses) difficulties can arise if the air circulation is restricted. Also, another disadvantage is that there is relatively little air circulation between the various rooms (when compared with forced air systems).

3.3 Zonal Heating System

The zonal heating system consists of unitary heaters located in each living space. Zonal systems permit room-by-room control of the amount of heat supplied and the method of heat transfer (ie convection or radiation). The different types of energy sources used by unitary heaters are electricity, gas, kerosene and oil. For zonal systems, an important factor is knowing the maximum heating load of each living space before the heaters are installed.

Zonal heating systems provide a high level of comfort by matching the heat supply to the use of the rooms. Like the hydronic system though, there is relatively little air circulation within the house.

3.4 Gravity Warm-Air Systems

Another type of heating system (which is almost obsolete) is the gravity warm air system. The gravity system has a heating unit located at the lowest house level, and utilizes the difference in density between hot and cold air to set up air currents and distribute the heated air. The distribution of hot air can take place either with or without a system of air ducts. The systems without air ducts use ceiling/floor registers and any openings between living spaces for air circulation.

The comfort of gravity warm air systems is very dependent on the amount of circulation between living spaces. Isolated rooms could therefore be difficult to heat.

4.0 SUPPLEMENTARY ELECTRIC HEATING EQUIPMENT

There are many manufacturers of supplementary electric heating equipment and therefore there are many subtle variations within the general categories of heating equipment.

This section will outline the general types of equipment within these categories. An attempt will also be made to identify the types of situations where the equipment would be most effective.

A summary of the applications of supplementary electric heating in existing heating systems is shown in Table 3.

4.1 Baseboard Heaters

Baseboard heaters are unitary heaters which are located along the floor (usually replacing the wooden baseboard) and are controlled by either unit-mounted or wall-mounted thermostats.

Baseboard heaters are available in 300 to 2500 W capacities, depending on the heater length and watt density. In many makes of baseboard heaters, flexibility in the heating capacity can be provided with additional smaller heating units. Also, in some heaters, flexibility in the heating capacity is obtained by using two stages of heating elements.

The main types of baseboard heaters available are radiant, convection and radiant-convection combinations. The heat from these units is typically transferred directly from electrical resistance elements. Some units though, use electrical resistance elements to heat water contained within the unit. The water then transfers the heat to the air by convection via a series of heat transfer fins, and thus allows a more gradual temperature change in the living space.

Portable baseboard heaters are also available but are less flexible in their sizes and are generally more conspicuous than regular baseboard heaters. They do provide a solution though for the more sporadic heating demands.

Baseboard heaters are best applied on outside walls and preferably under windows. This location allows convective heat transfer to counter the effect of the cold drafts and allow a more even temperature distribution in the living space. The radiative heaters must be carefully installed so occupants won't be in the shadow of tables or chairs and also so they don't receive heat on only one side of their body (ASHRAE/6/ studies show that heating only part of the body adds to the discomfort when the body temperature difference is beyond a certain range).

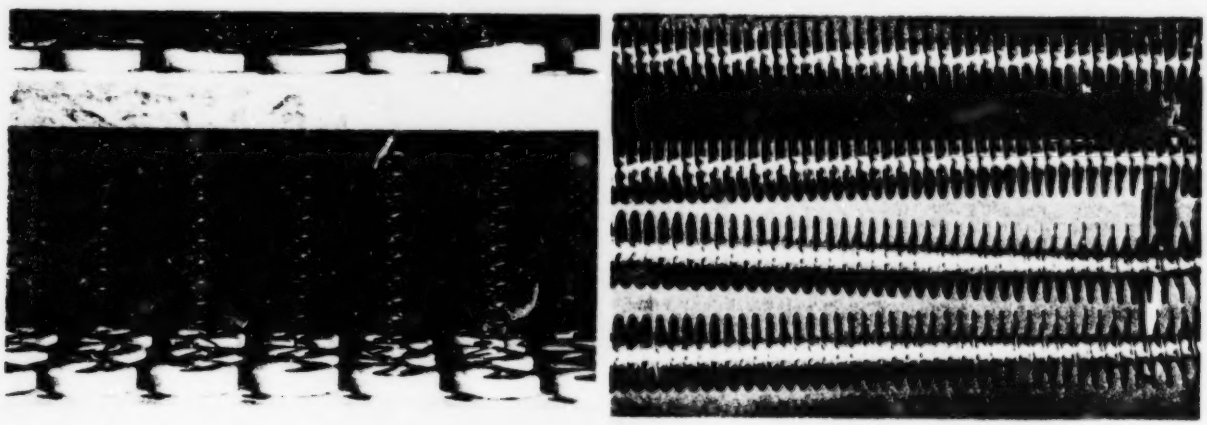
Baseboard heaters are an effective method of both conserving energy and improving comfort in a home with zonal temperature control.

The average cost to have baseboard heaters installed in a room is approximately $100 (note - this is an average value and is only meant to be used for comparison with other categories of heaters).

4.2 Plenum Heaters

A plenum heater is an electric heater certified for field installation in the plenum of a forced air furnace. Control of the heater is usually obtained with two-stage thermostats which monitor outdoor temperatures and starts the plenum heater when it can supply the heating demand, and the oil burner during the peak heating demands.

The types of elements available for plenum heaters are open coil and finned (see Figure 1). The open coil elements have the advantage of offering less of a restriction to the air flow than finned elements. The finned elements are more durable under fluctuating air flows than the open coil elements (less susceptible to hot spots).



a) open coil b) finned element

Figure 1
Types of Electric Elements on Plenum Heaters

There are two basic types of controls available with plenum heaters. The first type monitors the available power (after other household loads have been supplied) and determines whether there is enough power to satisfy the heating requirement using the plenum heater. If there is not enough power, the main furnace is operated. The second type is used when the electrical service entrance is large enough to operate the plenum heater in conjunction with the household loads, and therefore does not require load shedding capabilities.

The main application of plenum heaters is in oil furnaces where a large portion of the yearly oil consumption can be displaced. The cost to have a plenum heater installed is approximately $1000 (this is an average figure and is meant only for comparison with other categories of heating systems). This does not include an upgrade of the electrical service entrance which would be approximately $1000 more. A less expensive alternative to a service entrance upgrade is the plenum heater with load limiting controls, which costs approximately $1300 installed.

A characteristic of plenum heater operation is that the air temperature rise is less than it is during normal operation of the furnace. Therefore, during plenum heater operation, the supply air may feel cool to someone standing near an air register.

4.3 Add-On Heat Pumps

A heat pump is an electrically operated device which uses mechanical work to move heat from one location to another. The add-on heat pump transfers heat extracted from an external source (usually outside air) to a residence via a heat exchanger placed in the furnace plenum of a central forced air system. Cooling from heat pumps is obtained by reversing the cycle and transferring the heat from inside the house to outside. The schematic diagram of a heat pump system is shown in Figure 2. The control of a heat pump is usually achieved with a two-stage thermostat.

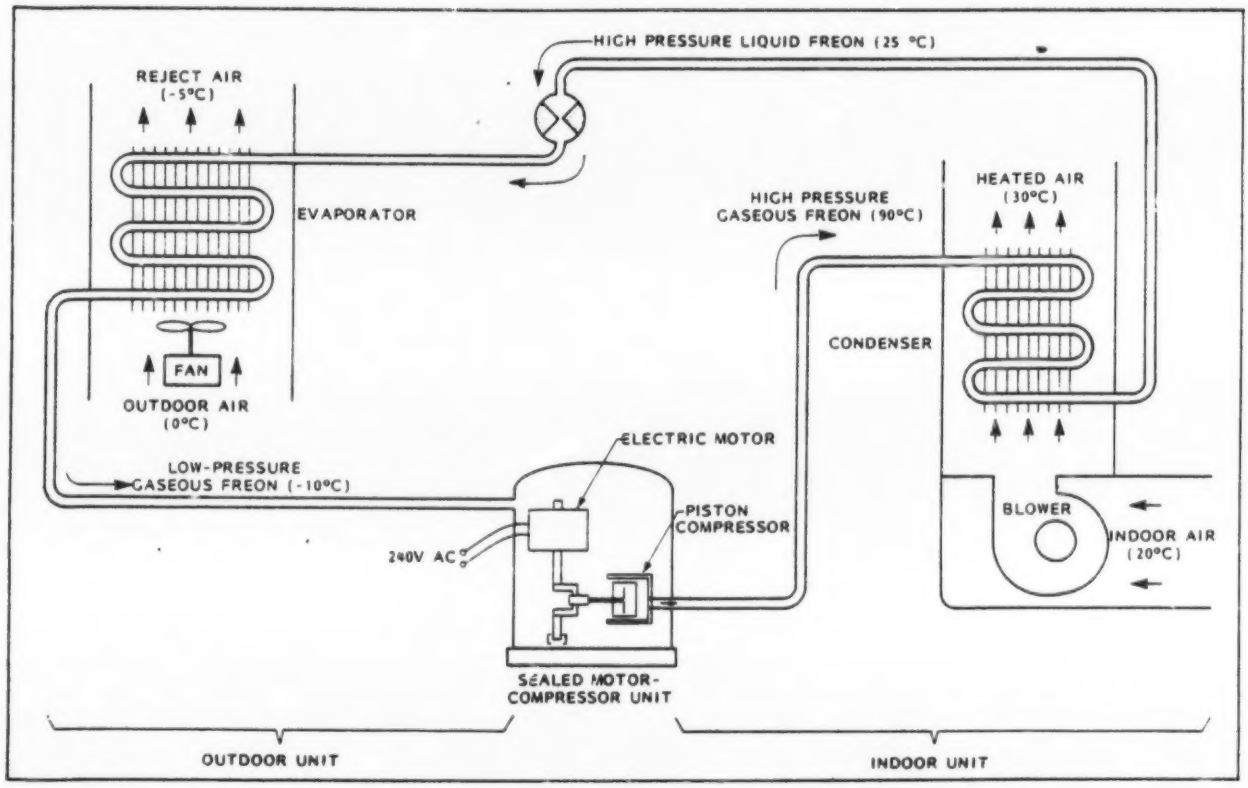


Figure 2
Schematic diagram of an air-source heat pump
in the heating mode

The main types of heat pumps available are air-to-air and water-to-air. The most common type of system is the air-to-air system which extracts heat from outside air and transfers it to the central forced air system. The water-to-air system uses either a series of underground pipes (ground source heat pumps) or well water (water source heat pumps) as the heat source.

The equipment available with the different heat pump systems is for the most part similar, but there are some variations. The indoor coils can be either the flat type coils (which take up less plenum space) or 'A' coils (which provide more heat transfer area). The most common types of compressors are the single and multi-stage reciprocating compressors, but centrifugal compressors are available with some water source heat pumps. The capacity of some heat pumps can be varied by using two stages of compressor power, or two stages of outdoor coils. Depending on the heat pump system, the compressor can be located inside or outside the residence. Also, heat pumps are now available with microprocessors which control the defrost cycle and indicate mechanical failures.

The average cost for a 2.5 ton heat pump installed, is approximately $3000 (note this estimate is an average value and is only meant to be used for comparison with the other categories of heating equipment). If the electrical service entrance needs to be upgraded, the additional cost would be another $1000.

4.4 Miscellaneous Equipment

Along with baseboard heaters, zonal heating can be provided by the following electric heating equipment.

4.4.1 Wall Unit Heaters

Wall unit heaters are designed for both surface and recessed mounting. Depending on the heater, the heat can be provided by convection, radiation, or fan forced convection. The fan forced heaters can usually be oriented to provide air circulation in any direction. The heating capacity of wall unit heaters is generally in the range of 500 to 5000 watts. They are suited for small or hard to heat areas (ie bathrooms, entrance halls, basements, etc).

Another type of wall unit heater is a kick space heater. They are available in capacities between 500 and 2000 watts. Their main applications are under kitchen cabinets or bathroom vanities.

A larger type of wall unit heater is the cabinet convector. They are available in sizes between 750 and 5000 watts and are best suited for areas with large heating demands (entrance ways, stair landings, etc).

4.4.2 Ceiling Units

Ceiling units are designed to transfer heat by radiation or fan forced convection.

The radiant heaters are usually in the form of panel heaters, cable heaters, ceiling insert units, or pendent units. They are available with heating capacities between 500 and 5000 watts. The operating temperatures of the radiant heaters range from up to 49°C for panel heaters, to between 260°C and 2760°C/4/ for infrared heaters (CSA/8/ states that ceiling heaters may operate above 280°C if there is appropriate sheathing, and if the heater is eight feet above the floor or grading). Radiant ceiling heaters are best applied in large spaces where it is more practical to heat objects as opposed to space heating.

The fan forced ceiling units have the advantage of directly providing air circulation in a room. Their most common application is in bathrooms.

In general, ceiling heaters will tend to increase the heat loss through the ceiling, but can provide comfortable heat if properly installed.

4.4.3 Portable Heaters

Portable heaters can provide heat by radiation, convection or forced convection. They are available in various physical sizes and shapes to fit in many types of spaces, and are available in heating capacities between 500 and 5000 watts. The main advantage of portable heaters is that they provide a method for meeting occasional heating demands. Extended use of portable heaters can affect the life of the circuit wiring, if the heaters load the electrical circuit close to its capacity.

4.4.4 Floor Insert Heaters

Floor insert heaters are convection or forced air heaters which fit between the floor joists with the output grille flush with the floor surface. They are available in 350 to 2000 watt sizes (between one and nine feet in length). They are best suited below floor to ceiling or floor level windows.

4.5 Controls

Automatic control of a living space's temperature is primarily achieved by using some type of thermostat.

Two categories of thermostats are line voltage and low voltage thermostats. Line voltage thermostats operate in series with the heating elements and therefore all the current passes through the contacts on the thermostat switch. Low voltage thermostats utilize a low voltage control circuit which includes a thermostat and a relay to switch the heating load.

The most common temperature sensitive switching device used in thermostats is the bi-metallic strip.[1] A device sometimes used in conjunction with the bi-metallic strip is an anticipator. The anticipator is a resistor which provides an internal source of heat to the thermostat when the contacts are closed. The heat is used to compensate for the time lag in the heat delivery of the heating system and reduces the temperature fluctuations in a living space by anticipating when the heat requirement will be met. During periods of constant heating demand though, the continuous internal source of heat causes a "droop" in the average room temperature (since the air at the thermostat is warmer than the average room temperature, the thermostat does not start the furnace when it should).

Another type of temperature sensitive device is a linear limit. The linear limit uses a thin tube which contains a gas under vacuum. The switch is opened when the gas heats up and expands. Another form of this device uses a reservoir of liquid at one end of the tube. As the liquid heats up, it expands along a certain length of the tube and opens the switch contacts. Linear limits are available mainly on baseboard heaters, electric boilers, and with two-stage thermostats (for monitoring outdoor temperatures).

In dual fuel systems, a special type of thermostat is used to control the two heating modes in different stages. The two-stage thermostats operate by monitoring the outdoor temperature (as an indication of the heating demand), and starting the appropriate heating mode.

The most recent developments in thermostats are electronic thermostats. One type that is available has programmable set-back controls, and specific models are available which can be programmed for up to seven day periods. The cost of a programmable set-back thermostat is approximately $75. Another type of electronic thermostat available proportions the amount of heat a baseboard heater delivers, according to the difference between the thermostat setting and the room temperature. The price of a proportional thermostat is essentially the same as a conventional thermostat (which is approximately $25). An

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[1] A bi-metallic strip consists of two strips of different metals connected along their length. Since the two metals have different thermal coefficients of expansion, when the ambient temperature changes, their lengths change in different proportions thus resulting in a tangential deflection. This deflection is then used to operate a switch.

advantage that the electronic controls have is that they should eliminate most of the "droop" associated with some bi-metal thermostats.

The most important factor affecting the comfort achieved with any thermostat is its location. In general, the thermostat should be located on an inside wall in a spot where conditions are representative of the room.

Another type of control that is available for dual fuel heating systems is a load shedding device. The load shedder monitors the total load at the service entrance and automatically sheds supplementary electric heating loads, as necessary to keep the service entrance load below 80% of its rating. The main advantage of the load shedder is that an expensive service upgrade can be avoided when supplementary electric heating is added. The cost of an installed load shedder is approximately $500 to $600 which is just over half the cost of a service entrance upgrade.

5.0 PROSPECTIVE DEVELOPMENT AREAS

The areas where development is occurring, and equipment may soon be available, are as follows:

1. Proportional controllers for electric furnaces and baseboard heaters using both phase angle control (chopping part of the current wave form) and pulsing of the power (energy to the electrical elements is turned on or off for varying portions of short cycles).

2. Further development of microprocessor controlled heat pumps.

3. Replacing sequencers (or thermal relays) on plenum heaters, with electronic timing relays.

4. Dual energy products in general to make heating systems more comfortable and more cost effective.

5. Dual stroke compressors on heat pumps which would allow a heat pump to operate at two heating capacities.

6.0 POSSIBLE AREAS OF ASSISTANCE FOR INCREASING SUPPLEMENTARY ELECTRIC HEATING ACCEPTABILITY

The acceptability of supplementary electric heating can be increased by any of the following ways. The first is to improve the level of comfort provided by the heaters. The second is to increase the financial benefits, and specifically to decrease the payback period of the supplementary heating equipment. The third is to increase the reliability of the heating equipment.

One area of development which could increase the level of comfort provided by plenum heaters is a proportional controller for plenum heaters. Proportional heat control would increase comfort by reducing the fluctuations in the room temperatures. It may also have an adverse affect on comfort though, as it will reduce the average temperature of the delivered air (see Section 3.2). The design of this device would be a simple extrapolation from the controls being developed for electric furnaces. Assistance that Ontario Hydro could provide with this device could be in the form of laboratory and field tests to more accurately determine the effect on comfort.

Another device, which could complement a plenum heater proportional controller, is a furnace blower controller. This device would control the temperature of the supplied air by adjusting the speed of the blower fan. It could also be used to supply steady air circulation at a low rate. Work has already begun to design such a device, but further work could be in the form of field tests to evaluate its affect on comfort.

The newer heat pumps with microprocessors will provide a more energy efficient method for defrosting the coils. Also, since diagnosis constitutes a large portion of mechanical repairs, the feedback on mechanical failures will allow more customers to make their own repairs. This will help reduce repair costs and the amount of time when the heat pump is inoperative. Assistance with this equipment could be in the form of testing the heat pumps to assist in overcoming the problems associated with first generation equipment.

7.0 CONCLUSIONS

1. Forced air systems have the most possibilities for supplementary heating (see Table 3) and are the most common heating system in existing homes.

2. Comfort problems can become economic factors if they cause the occupant to turn up the thermostat setting (as affected by such factors as thermostat location and temperature droop).

3. Future development from the manufacturers of electrical heating equipment seems to be focused mainly on dual fuel systems.

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